

Lithium-Ion Small Cell Battery Shorting Study

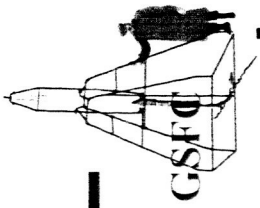
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(AEA Technology)

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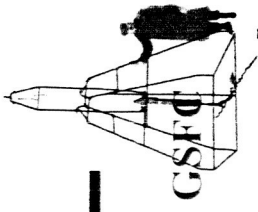




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- Test Plan
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 - Summary
- Conclusions



Background: History

- NASA/Johnson Space Center (JSC) identified Battery hard short issue during Electric Auxiliary Power Unit (EAPU) project
- NASA/Goddard Space Flight Center (GSFC) encouraged AEA to understand process and mitigation strategy for unmanned work
- AEA conducted hard short study under internal funding

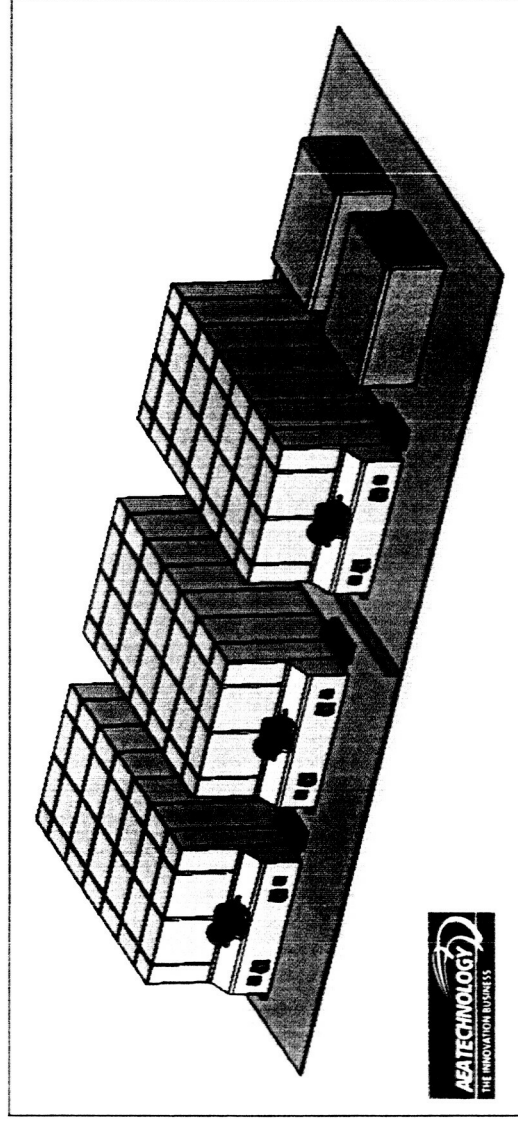
• Understanding Positive Temperature Coefficient (PTC) limitation was critical to

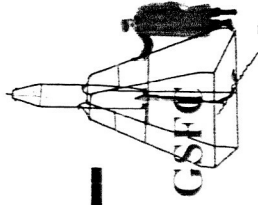
AEA winning the Advanced

Hydraulic Power System

(AHPS) contract

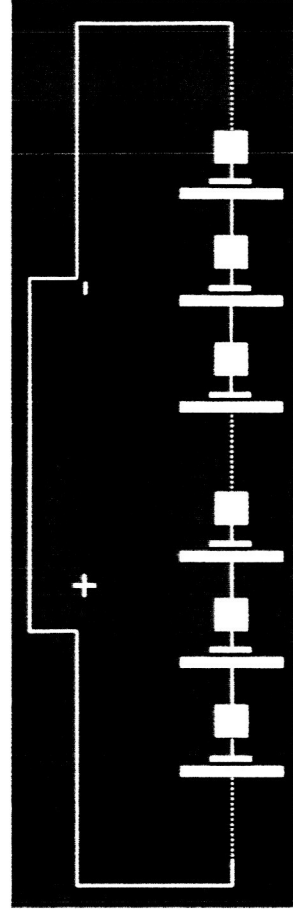
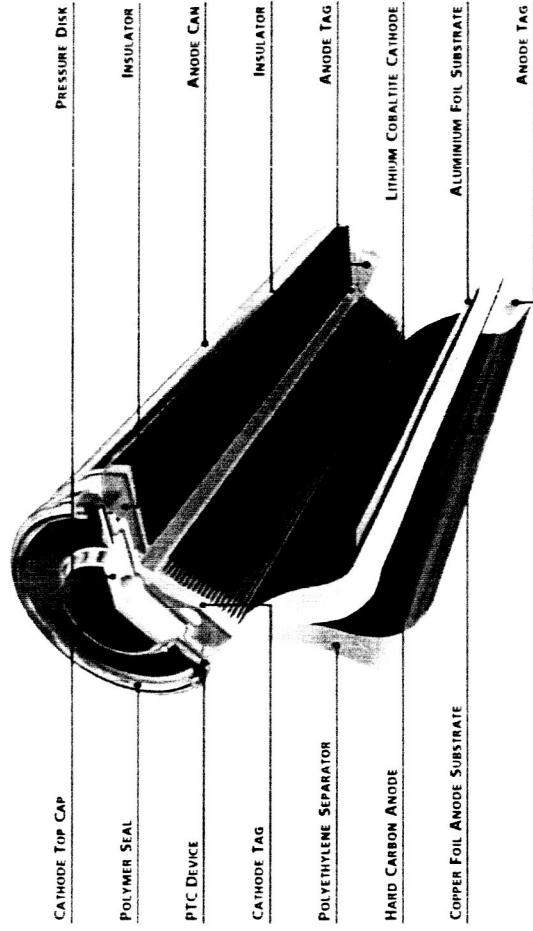
• Diode scheme implemented for AHPS (86s) battery passing safety segment of Interim Design Review

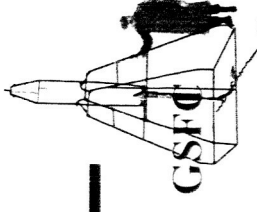




Background: PTC Functionality

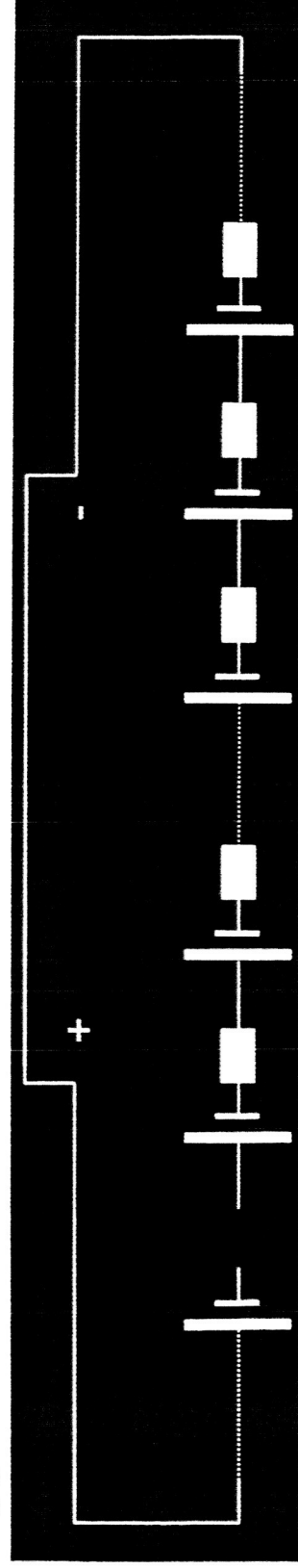
- PTC is a standard safety feature in the SONY 18650HC Lithium-Ion small cell
- PTC is a temperature dependent resistor in series with cell
- At high current, temperature rise triggers resistance rise in PTC stopping current flow
- PTC mitigates high energy events associated with short circuit
- Key safety benefit of the small cell approach



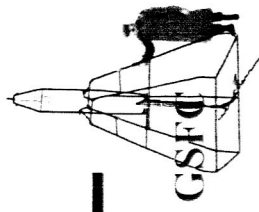


Background: PTC Limitations

- Series-PTC can fail short circuit if sufficiently high voltage is applied

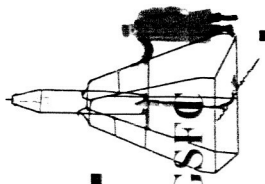


- In event of sustain low impedance hard short across battery terminals, no protection if voltage is higher than rating
- Cells become increasingly hot, venting can occur
 - However, much less energetic event than in a large cell
- Possible safety issues
 - ground handling
 - manned space applications



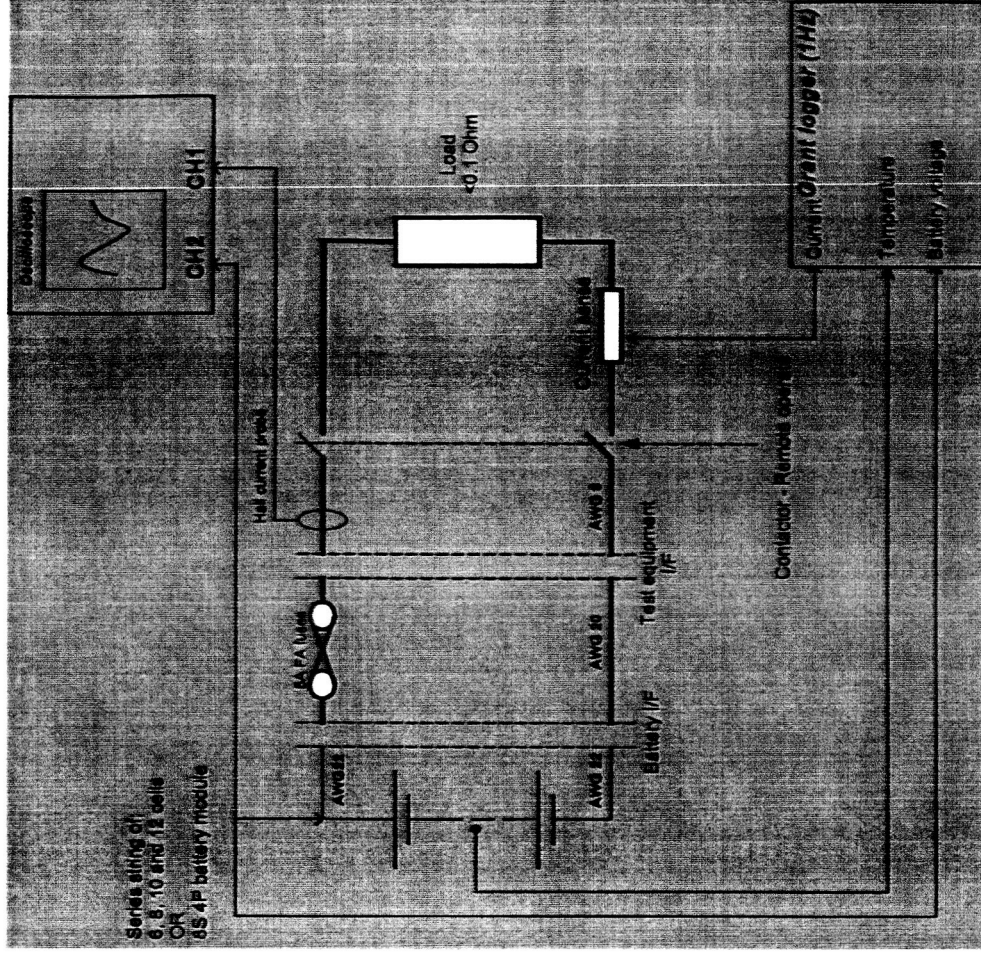
Test Plan

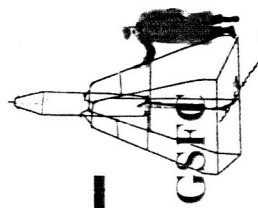
- Hard Short Single (1p) String Tests
 - 6s
 - 8s
 - 10s
 - 12s
- Battery Module (8s4p) Tests
 - 2C discharge test
 - Hard short with fused saver
 - Hard short without fused saver



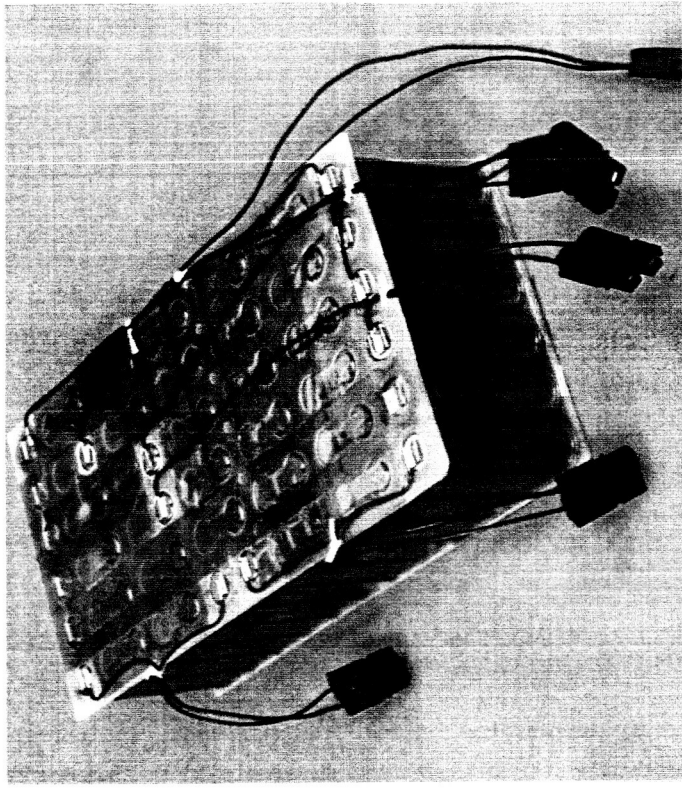
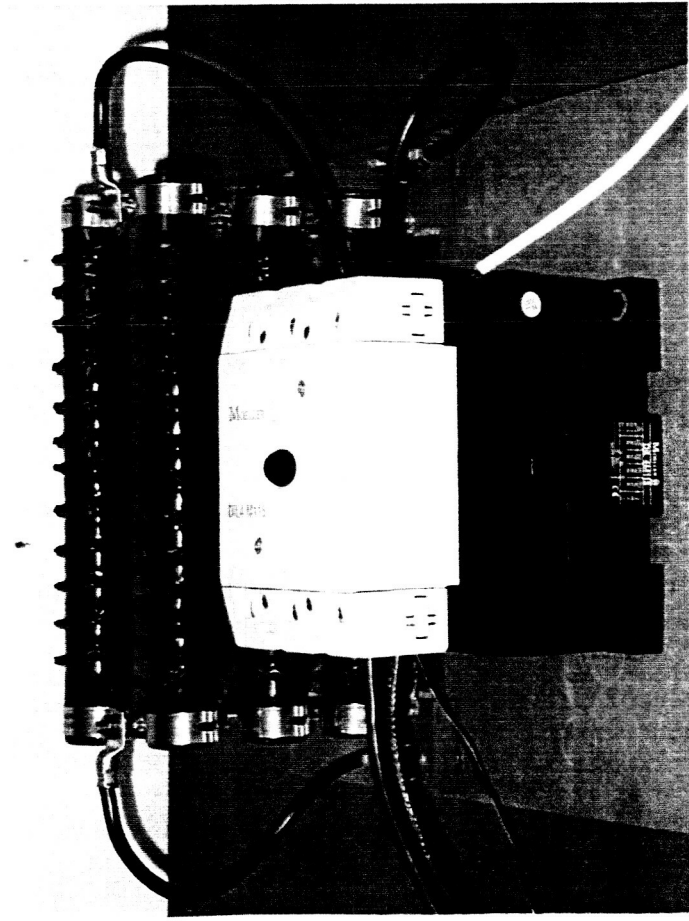
Test Results: Single String Test Set Up

- Test set up for controlled short circuit
- Recorder to log temperature, voltage and current during short circuit
- Oscilloscope to capture fast transients
- Remote operation

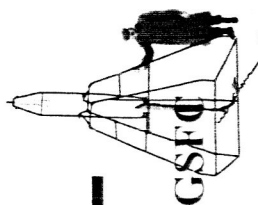




Test Results: Single String Test Hardware

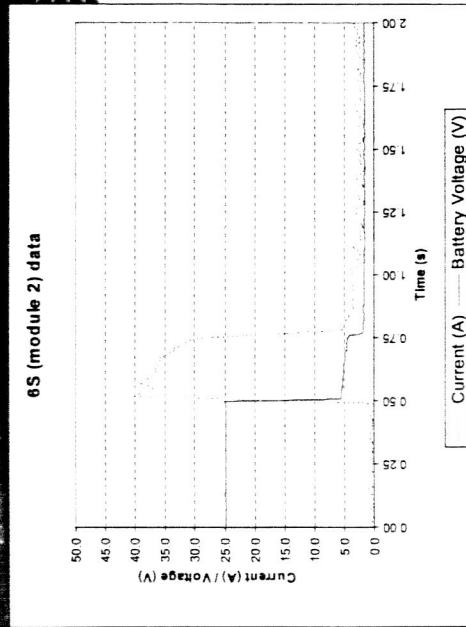
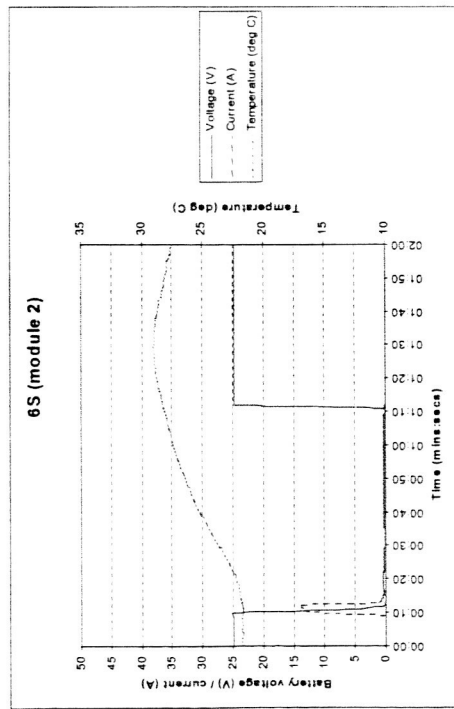
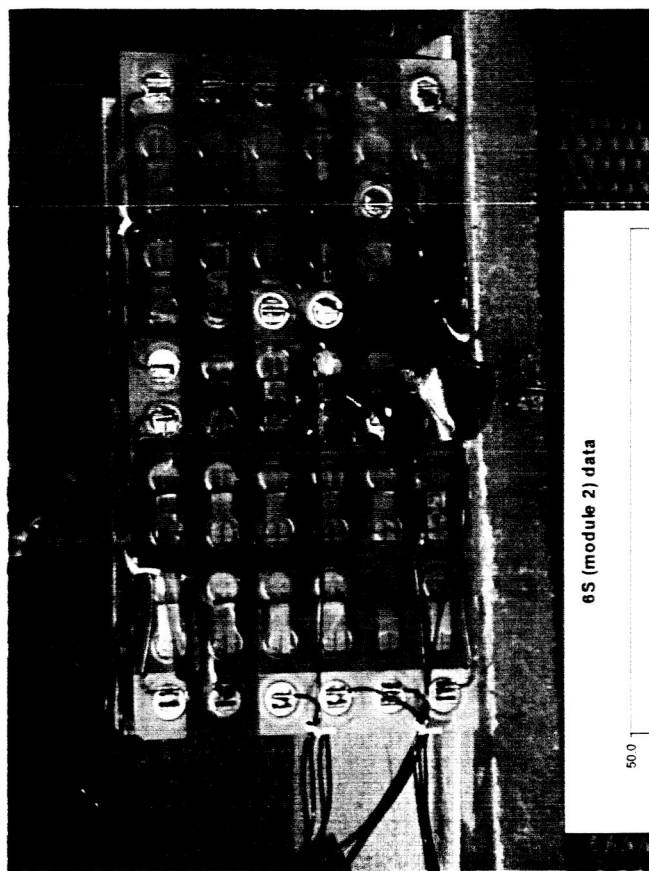


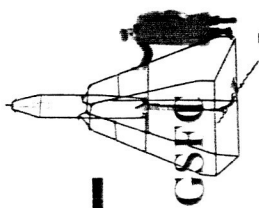
- AEA built low resistance relay block
- Single battery block split into strings



Test Results: Single String 6s1p Sustained Short

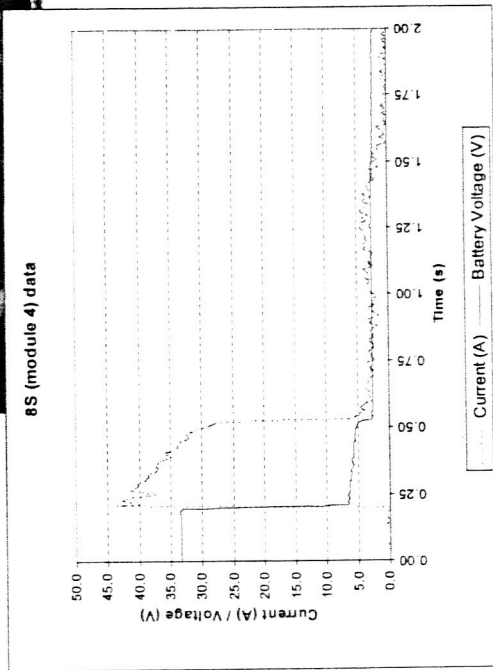
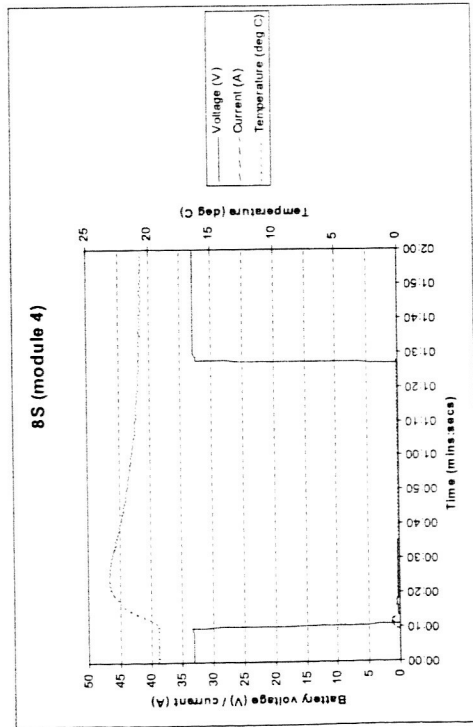
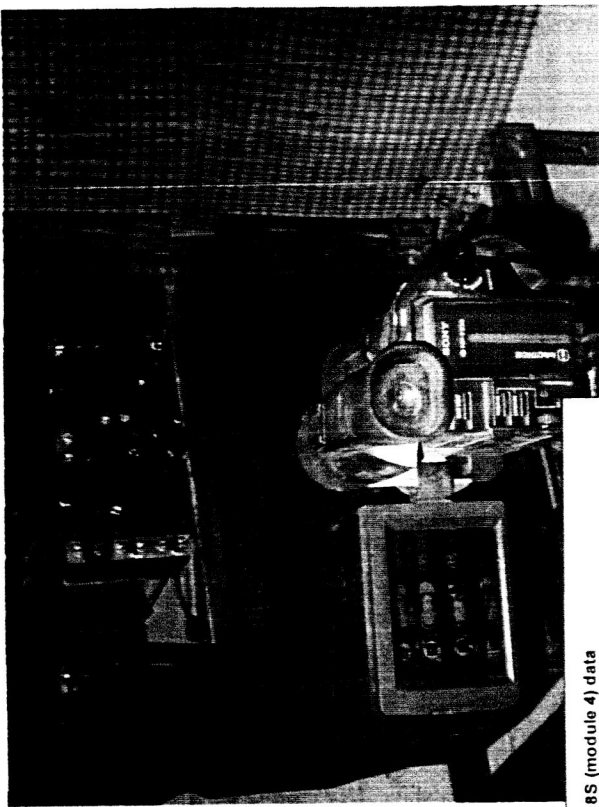
- PTC activates in 0.5 sec.
- Temperature rise 8°C
- PTC ensures safe shutdown

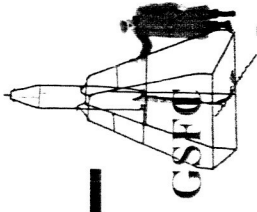




Test Results: Single String 8s1p Sustained Short

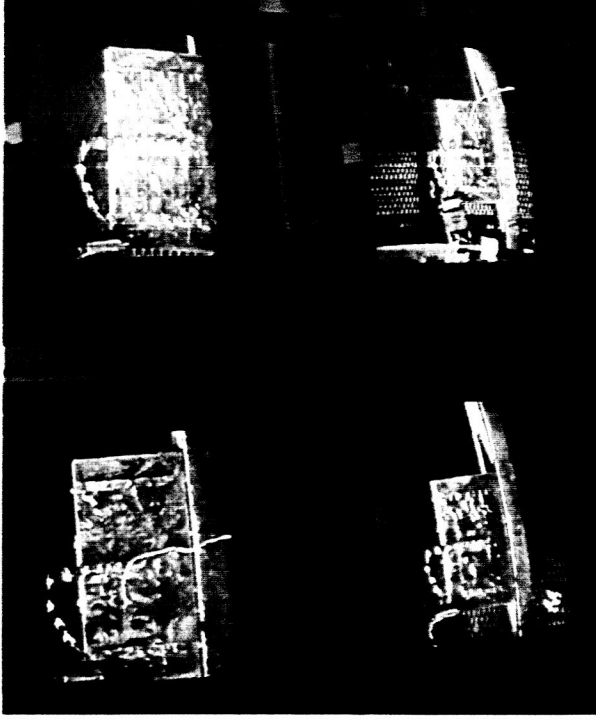
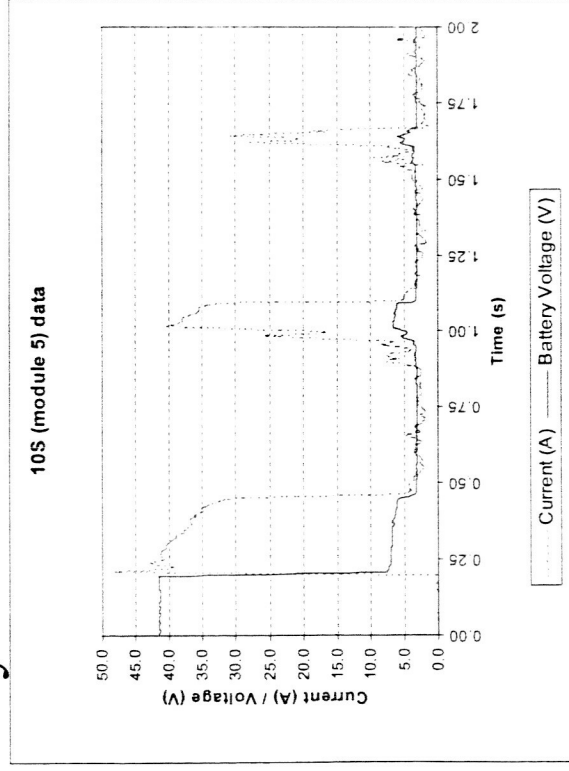
- PTC activates in 0.3 sec.
- Temperature rise 2°C
- Maximum current 42 A



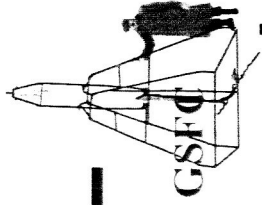


Test Results: Single String 10s1p Sustained Short

- PTC initially activates in similar manner to 6s & 8s test
- 1st PTC breaks down after 0.5 sec.
- Succession of PTC activation followed by breakdown

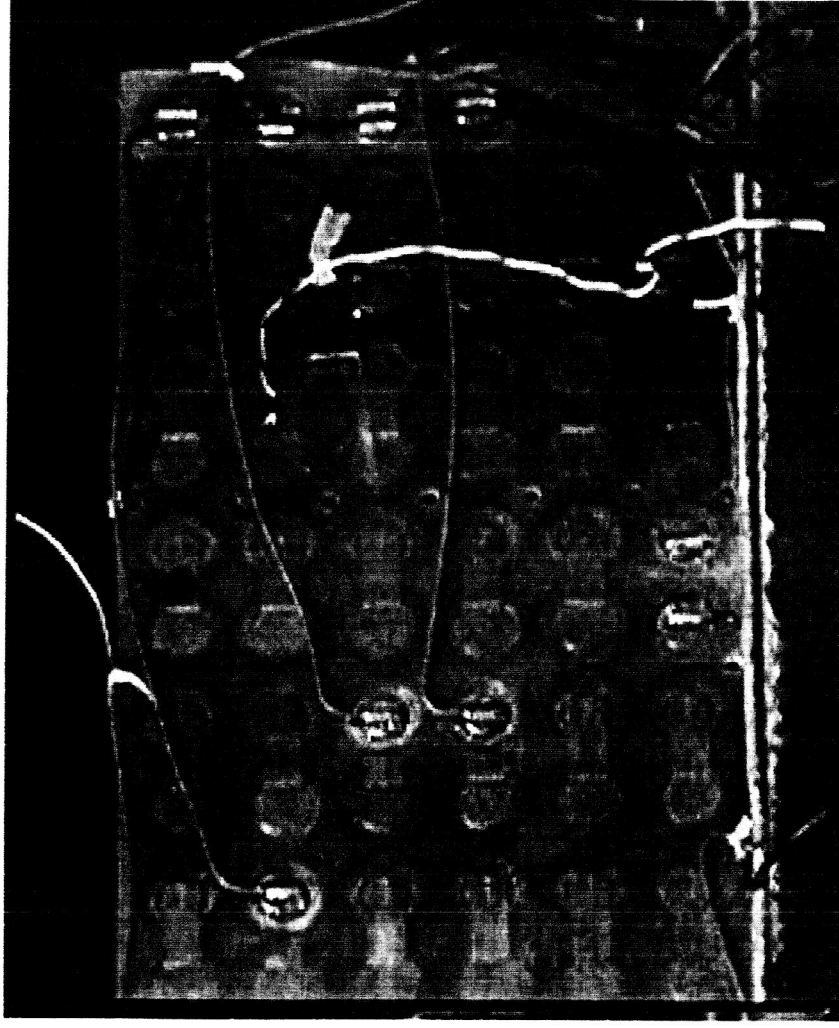


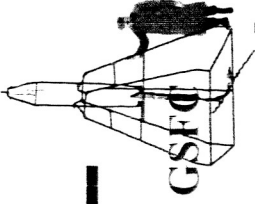
- Temp rises to 28°C after 40 sec.



Test Results: Single String 10s1p Sustained Short

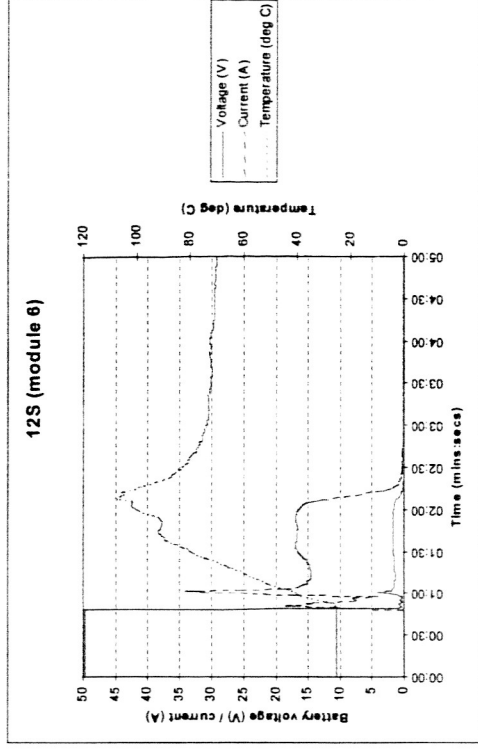
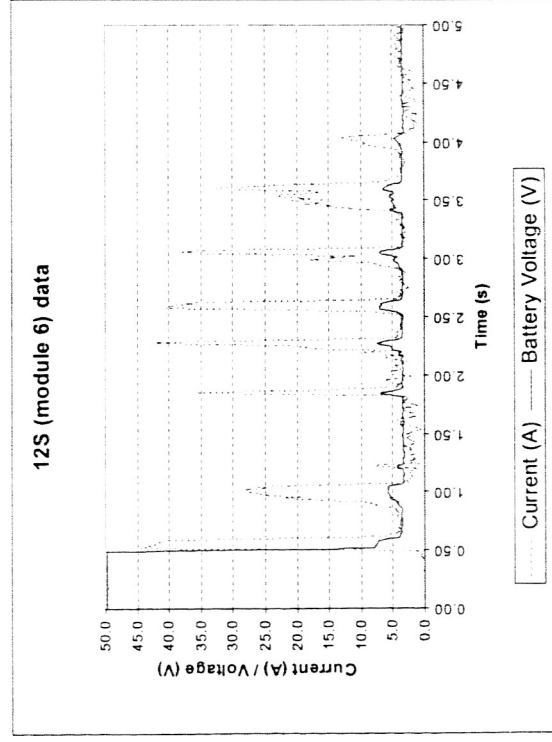
- Small sparks
- Cell vent
- Electrolyte leak
- No smoke
- No fire





Test Results: Single String 12s1p Sustained Short

- PTC initially activates in similar manner to 6s & 8s test
- 1st PTC breaks down after 0.5 sec.
- Succession of PTC activation followed by breakdown



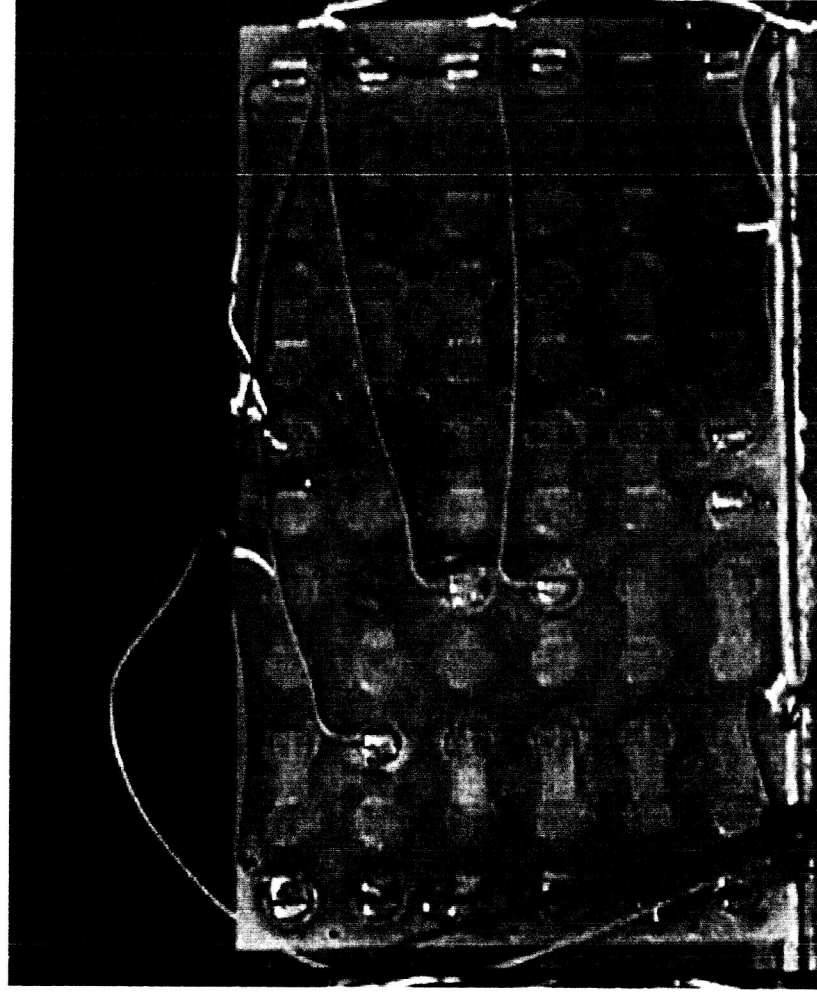
- 17 A sustained for 2 min.
causes temperature to rise to 110°C

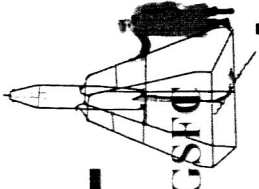


Test Results: Single String 12s1p Sustained Short



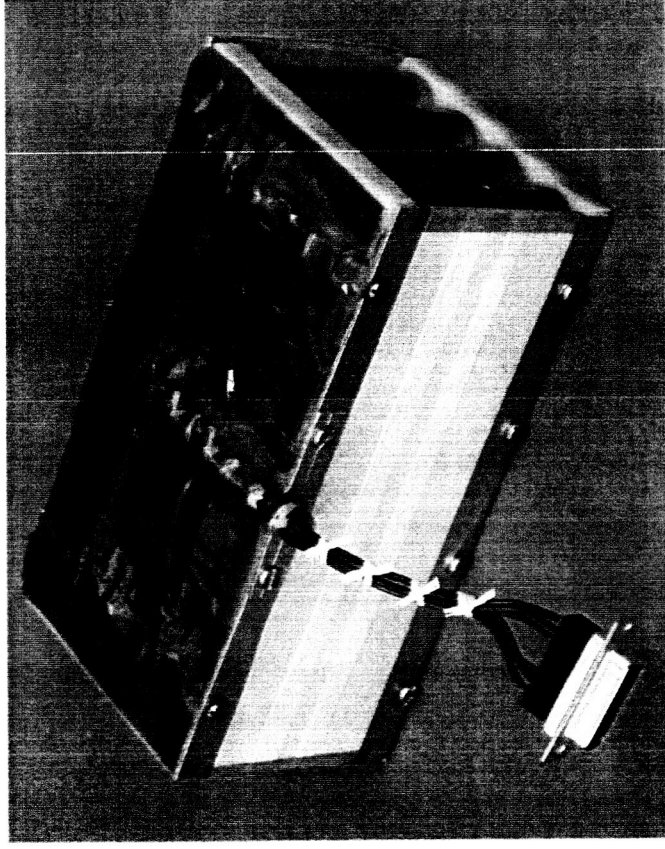
- Small sparks
- Cell vent
- Electrolyte leak
- No smoke
- No fire

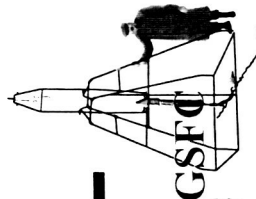




Test Results: Battery Module Test Hardware

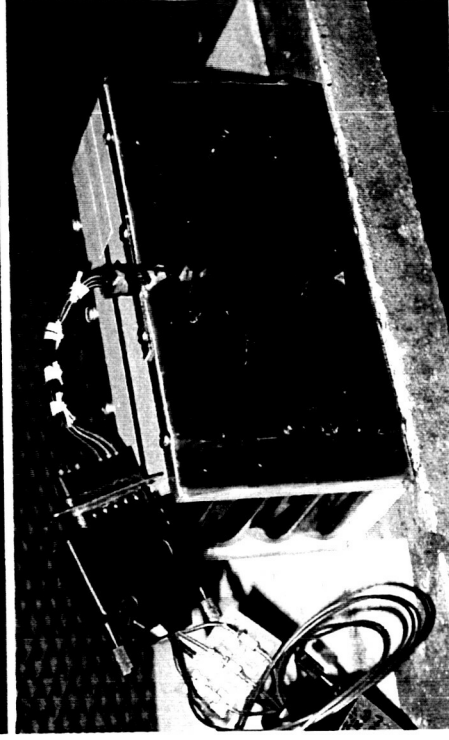
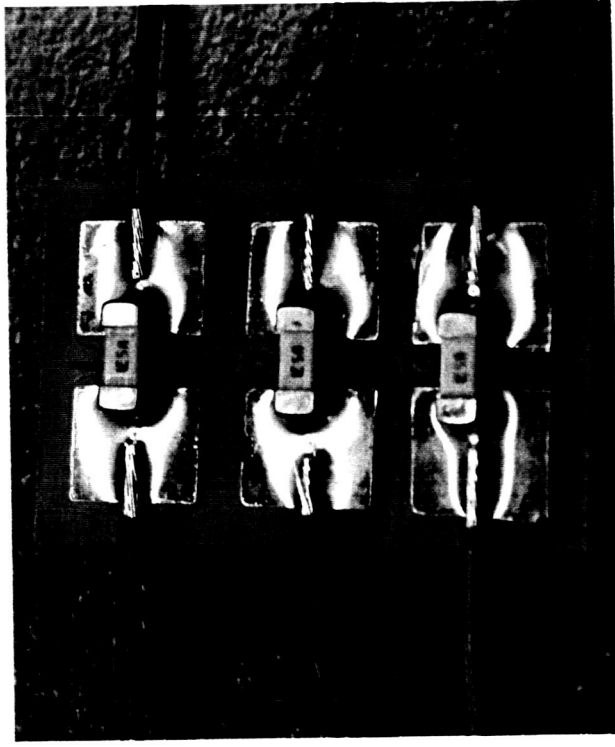
- Dedicated battery module
 - 8 cells in series
 - 4 strings in parallel

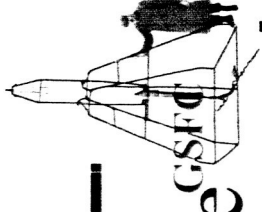




Test Results: Battery Module Test Hardware

- Fused connector
 - Ensures protection against short during Integration and Testing
- Standard AEA equipment
- Fuses sized
 - To ensure nominal battery performance is unaffected
 - Rating of wiring is not exceeded
- Inexpensive item
- Removed prior to final spacecraft integration





Test Results: Battery Module Test Procedure

TEST 1:

- 2C discharge for 15 min. with the fused connector

TEST 2:

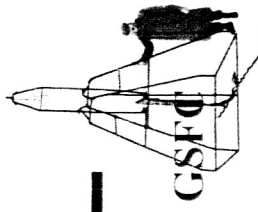
- Hard short with fused connector

TEST 3:

- Hard short without fused connector

During All Tests:

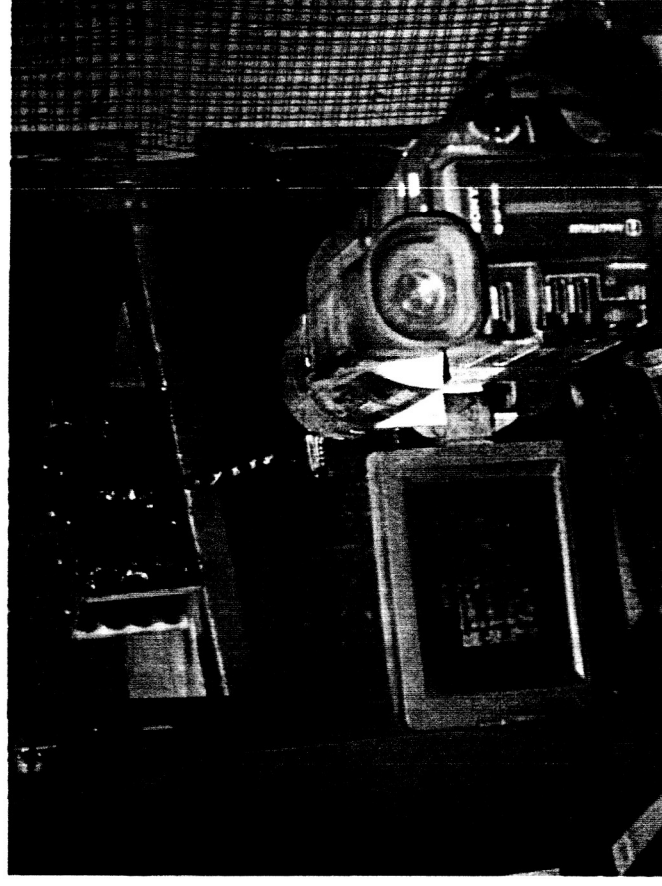
- Battery Voltage/ Current monitored
- Visual observation for any smoke, sparks or vent

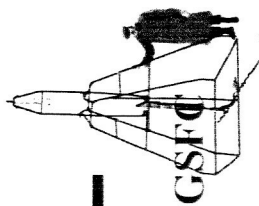


Test Results: Battery Module Test 1

2C discharge test

- Battery delivers 2C for 15 min.
- Slight rise in temperature
- Fused connector not activated
- PTC not activated
- Post test AEA Standard Capacity Measurement (SCM) confirmed battery health

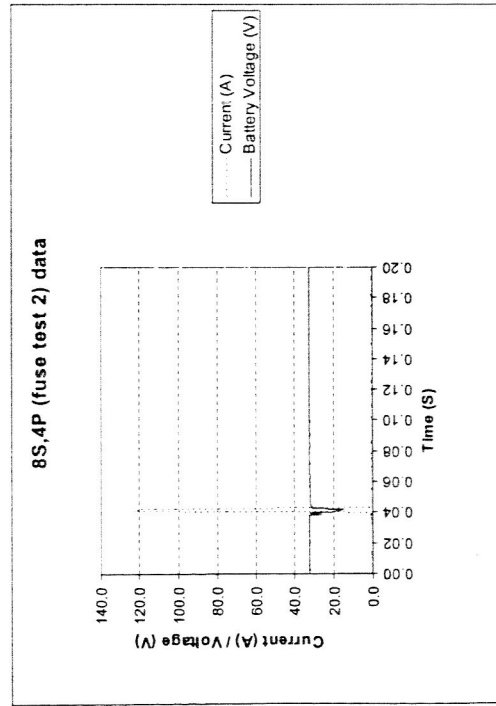
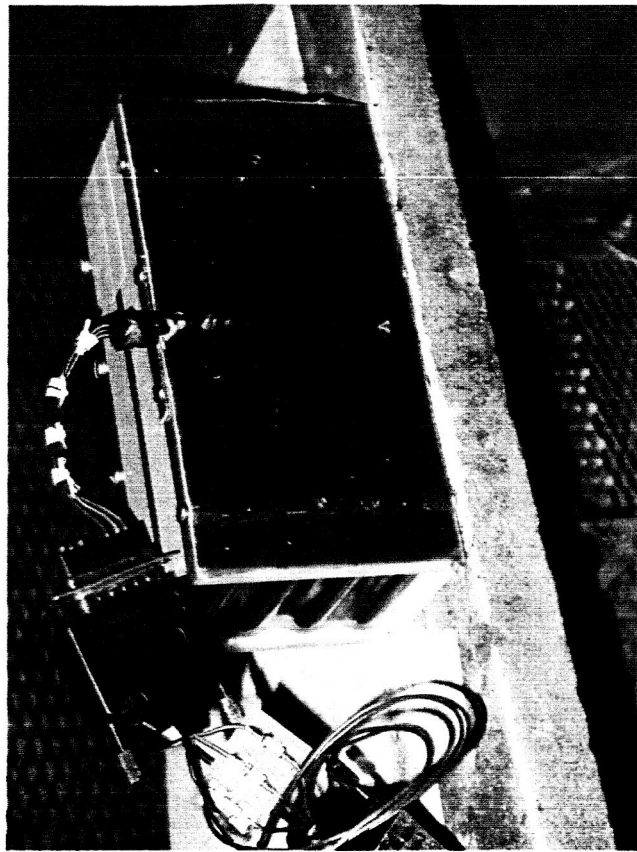




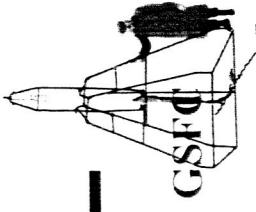
Test Results: Battery Module Test 2

Hard Short Test With Fused Connector

- Protective fused connector instantaneously activates
- No rise in temperature
- PTC not activated



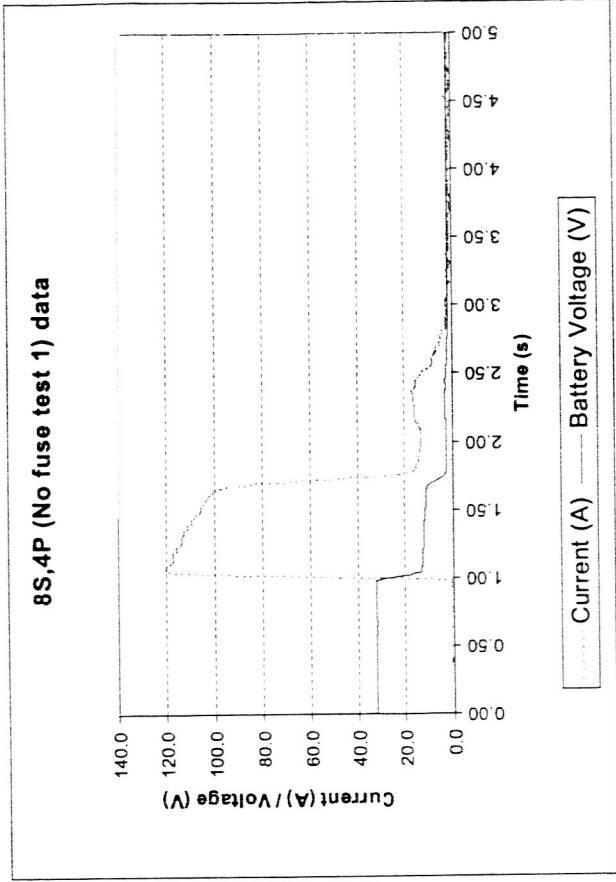
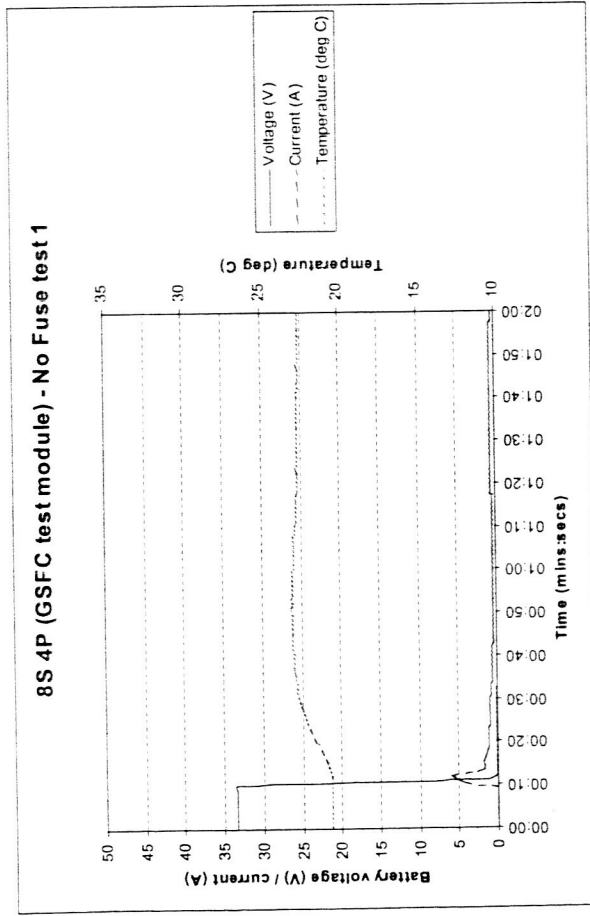
- Post test SCM shows no affect on battery
- Fuse activates within 0.05 sec.
- High current transient around 120 A

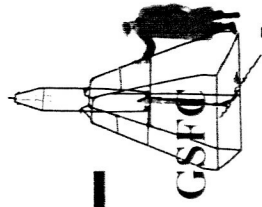


Test Results: Battery Module Test 3

Hard Short – No Fused Connector

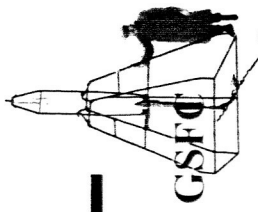
- PTC operated nominally
- Safe shutdown
- No visual events





Test Results: Summary

Cell Configuration	Result
6s1p	PTC Activates Nominally – safe shutdown
8s1p	PTC Activates Nominally – safe shutdown
8s4p	PTC Activates Nominally – safe shutdown
10s1p	PTC breakdown – short circuit
12s1p	PTC breakdown – short circuit



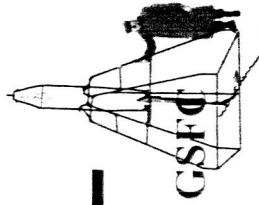
Conclusions

- PTC provides adequate sustained hard short protection for AEA batteries with up to 8 cells in series
- PTC cannot protect against sustained hard short in AEA batteries with 10 cells or more in series
- Protective fused connector is a proven way to protect larger batteries from hard short damage
 - Hard short not credible in unmanned missions
 - However, recommended during ground handling
 - Inexpensive item
- Preliminary diode protection scheme has passed manned space safety requirements for high voltage batteries
- SCM confirmed fused connector did not affect battery health
 - However, this affect of hard short on the its long calendar and cycle life performance needs to be verified.



Acknowledgements

- Dr. Eric Darcy, NASA/JSC
- Don Lester, ASTRIUM



Lithium-ion Small Cell Battery Shorting Study

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AEA performed a hard short study on various cell configurations whilst monitoring voltage, current and temperature. Video recording was also done to verify the evidence for cell venting. The presentation summarizes the results of the study including video footage of typical samples. Need for the diode protection in manned applications is identified. The standard AEA approach of using fused connectors during AIT for unmanned applications is also described.